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Effects of Guide Vane Inclination Patterns on Threshing Losses and Power Requirement

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ABSTRACT

A survey and also performance evaluation were undertaken of the guide vane inclination patterns in axial flow threshing units. The study involved two stages: 1) surveying the patterns of the guide vane inclination of rice combine harvesters and 2) studying the effect of the guide vane inclination on the threshing loss and the power requirement. The experiment was performed using the tester threshing unit of the Postharvest Technology Innovation Center, Khon Kaen University. There were three major findings. 1) Guide vane inclination can be adjusted using three patterns—namely, Group 1, where the guide vane inclination of the first 3 blades from the input was smaller than the last 2 blades; Group 2, where the guide vane inclination of all blades on average was similar; and Group 3, where the guide vane inclination of the first and last blades from the input was smaller than the blades at the center of the threshing chamber. 2) The guide vane inclination patterns studied did not have a significant effect on grain breakage, but did on threshing losses and power requirements. 3) The pattern of the guide vane inclination of axial flow rice threshing units for harvesting the Chainat 1 rice variety should be one where the inclination angles consistently increase through 69, 71, 73, 75 and 77 degrees from the threshing axial when the rotor speed is 18 $m.s^{-1}$ and the feed rate is 16 $t.hr^{-1}$.

Keywords: Thai combine harvester, guide vane inclination, threshing unit loss, power-requirements.

INTRODUCTION

Rice is an important cash crop of Thailand, with productivity of approximately 30 million t of paddy rice annually valued at THB 300,000 million (approximately USD 9,375 million) and in 2010, rice exports accounted for 10.21 million t, or THB 184,000 million (approximately USD 5,750 million; Imsil, 2011; OAE, 2010). Harvesting is considered an important step in rice production which has an impact on both the amount and quality of rice (Junsiri and Chinsuwan, 2009; Zhao *et al.,* 2011). Losses from harvest bring detrimental effects to the country's economy. A one percent loss of paddy rice from harvest leads to a loss of THB 3,000 million (approximately USD 94 million) in revenue. Hence, a reduction in harvest losses is a necessity. At present, rice combine harvesters are being used widely, with about 10,000 combine harvesters estimated to be operating currently in paddy fields all over the country and the trend is increasing (Chinsuwan, 2010). The use of a rice combine harvester can reduce the harvest loss by 3% (Chinsuwan *et al.,* 1999) apart from saving time, cost and labor during harvesting.

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Chuan-Udom and Chinsuwan (2010) investigated harvest loss due to the use of rice combine harvesters for Khao Dawk Mali 105 (KDML 105), which is a common indigenous rice variety. The average harvest loss was 3.16% of the total paddy rice, from which 58.94 and 34.17% of harvest loss were from harvesting and separating grain from ear, respectively. When a rice combine harvester was used on off-season rice, the harvest loss averaged 6.81% of which 87.59% of the harvest loss was from grain separation because most off-season rice is hybrid for which it is more difficult to split the grain than in indigenous rice. At present, entrepreneurs or owners of combine harvesters adapt their harvesters for renting, especially the guide vane inclination, which determines the flow rate of paddy bundles into the threshing chamber (Chuan-Udom and Chinsuwan, 2011). These adaptations can result in losses from threshing and separating grain from ear (Waingwisad, 2011). In adjusting the guide vane, each entrepreneur uses different patterns of guide vane angles depending on experience without considering the loss that occurs, especially from the threshing unit.

Loss from threshing using an axial flow combine harvester for Chainat 1 (a hybrid variety) was computed by Chuan-udom (2007). The grain moisture content had the highest effect on loss, followed by the guide vane inclination from the threshing axial. The guide vane inclination is the angle measured from the horizontal in an anticlockwise direction. The rotor speed and feed rate had little effect on loss. In threshing KDML 105, which is an indigenous rice, it was found that the guide vane inclination had the greatest effect on loss from the threshing unit, followed by rotor speed (Chuan-udom, 2007). It can be seen that the guide vane inclination resulted in a relatively large loss in hybrid and indigenous varieties. In addition, the study by Harrison (1991) on threshing power and loss in an axial flow thresher operated with barley, while is different from Thai rice, showed that the guide vane inclination had an important effect on both the power requirement and loss from the threshing unit. Chuan-udom and Chinsuwan (2009) used a prediction equation and predicted threshing loss from Thai axial flow combine harvesters processing KDML 105. They found that the guide vane inclination should be at least 66 degrees from the threshing axial, so that the threshing loss was less than 1%.

The problem discussed reveals that the guide vane inclination is an important operating factor with an impact on the threshing loss and power requirement. A study on appropriate guide vane inclinations would provide information necessary for relevant organizations that organize training to entrepreneurs running businesses using rice combine harvesters. They would be aware of an appropriate guide vane inclination for their harvesters working with hybrid varieties, especially Chainat 1, which is a common Thai hybrid. Thus, this study surveyed and undertook performance evaluation of guide vane inclination patterns of an axial flow threshing unit.

MATERIALS AND METHODS

This study was divided into two stages—guide vane inclination adjustment for rice combine harvesters and the effects of the guide vane inclination adjustment on the threshing loss and power requirement.

Survey of guide vane inclination adjustments of rice combine harvesters

The guide vane inclination patterns of 17 rice combine harvesters were surveyed (Table 1). Baseline harvester data included the size of threshing units and the guide vane inclination patterns. The guide vane geometry was measured from the distance from the end of the guide vane at the back of the threshing unit to the concave rod in front of the threshing unit (Y) and the distance between the end of the guide vane in front of the threshing unit and the concave rod (X) as shown in Figure 1. The guide vane inclination (θ) was calculated based on trigonometric principles using Equation 1:

$$\theta = \tan\text{-}1\ (Y/X) \quad (1)$$

where θ is the guide vane inclination measured in degrees, X is the distance in centimeters between the end of the guide vane in front of the threshing unit and the concave rod and Y is the distance in centimeters from the end of guide vane at the back of the threshing unit to the concave rod in front of the threshing unit.

The data were analyzed by grouping similar guide vane inclinations together (Table 2).

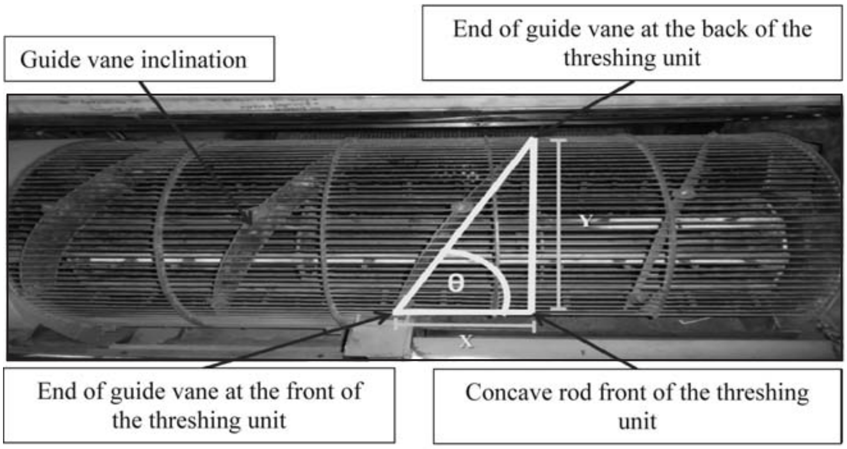

Figure 1 Measuring guide vane inclination. (X,Y are measured to determine θ, the guide vane inclination.)

Table 1 Summary of guide vane inclination adjustments for 17 rice combine harvesters.

Guide vane inclination adjustment group	Machine number	Order of angles of guide vane inclination from input (degrees)				
		1st	2nd	3rd	4th	5th
1	1	65	65	66	66	70
	2	74	76	78	80	80
	3	74	74	75	82	83
	4	68	72	72	74	-
	5	63	68	77	76	-
2	1	72	72	71	71	71
	2	64	63	64	64	64
	3	66	67	66	66	72
	4	71	70	68	69	69
	5	69	69	69	71	72
	6	69	70	70	69	69
	7	72	73	73	73	71
	8	68	68	68	68	68
	9	69	70	70	71	72
	10	68	69	68	68	-
3	1	68	76	76	66	-
	2	69	73	73	70	-

Then, the guide vane inclination patterns obtained were compared by considering the possibility of reducing the threshing loss and power requirement. In the study, six patterns of guide vane inclination were tested.

Study of the effect of guide vane inclination adjustments on threshing loss and power requirement

Equipment used in the test

The threshing unit used in the test was located at the Farm Machinery and Postharvest Technology Center, Department of Agricultural Engineering, Khon Kaen University. The unit's rotor speed and feed rate can be adjusted. In the test, the thresher discharged paddy rice onto a tray with long cavities to receive the rice from which a sample was collected in a sample bag. There was a device measuring the shaft's torque to study the power requirement.

The threshing unit was 1.70 m long, with a diameter towards the end of the peg tooth of 0.70 m and the peg tooth height was 80 mm. The eight threshing bars were straight. Peg teeth were round and 11 mm wide with a clearance of 77 mm between teeth. The lower mesh had an arc radius of 0.39 m. The steel mesh was round and 8 mm wide with a gap between the mesh of 17 mm. There were five lines of lower thresher unit with equal gaps, and the height of the mesh rim from the surface of the mesh wire was 5 mm. The straw-discharge blades were upright. There were five guide vanes in the unit. (Figure 2).

Factors studied

This research studied the effect of the guide vane inclination on the performance of an axial flow rice threshing unit. The threshing unit was designed to function under relatively difficult conditions according to the principle that if a threshing unit can work under such conditions, it should be able to work under less difficult conditions. Therefore, the test was performed on relatively long paddy bundles. The feed rate was constant at 16 $t.hr^{-1}$, the highest possible rate that the threshing unit could cope with. The linear speed at the end of the peg teeth was 18 $m.s^{-1}$ (491.11 rpm). A sample of 30 kg of rice was used for each test with three replications. The grain

Table 2 Comparison of rice combine harvesters in each group.

Guide vane inclination adjustment group	Number of rice combine harvesters	%
1	5	29.4
2	10	58.8
3	2	11.8
Total	17	100.0

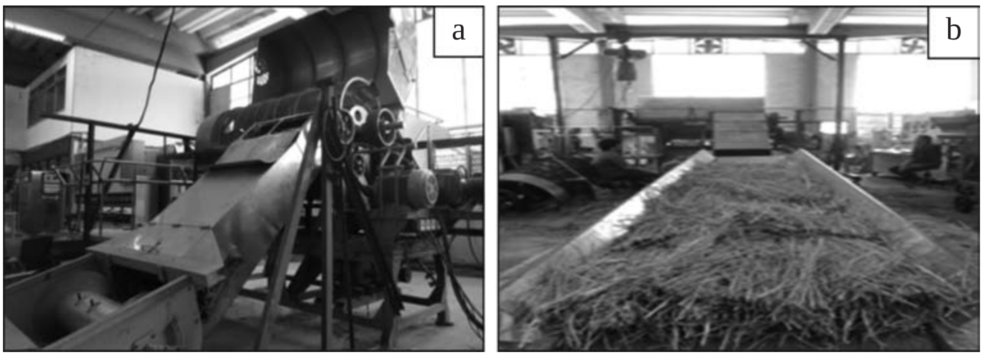

Figure 2 (a) Tester threshing unit and (b) Feeder.

and straw moisture contents, length of stalks and the ratio of grain-to-straw by fresh weight were measured.

Six patterns of guide vane inclination were tested (Table 3). The first, second and third patterns were obtained from the 17 rice combine harvesters surveyed. The fourth pattern was obtained from the study by Chuan-udom (2011) on the effect of the guide vane inclination of axial flow threshing units on the threshing loss and power requirement when working with Chainat 1. From this study, the guide vane inclinations of the input and output sections should be 60 and 70 degrees so that the threshing loss is low.

Patterns 5 and 6 were new ones according to the concept of reducing the loss and power requirement from the threshing unit. The concept of pattern 5 was to move material quickly from the input section (by adjusting the guide vane inclinations of blade numbers 1 and 2). Pattern 5 allowed the material to stay longer in the output section (by adjusting the guide vane inclinations of blade numbers 3, 4 and 5) to enable longer threshing and longer processing to separate the paddy rice from the ears. Consequently, the guide vane inclinations of the input section were 60 degrees because of the higher density of the materials. The guide vane inclinations should not be more than 63 degrees in order to reduce the power requirement but must not be less than 60 degrees because this would result in insufficient movement of materials in the threshing unit (Chuan-Udom, 2011). The guide vane inclinations of the next blades in the output section were 63, 66 and 70 degrees, respectively, because most of the material in this section was straw from which the grain had already been separated from the ear and was material being ejected from the combine harvester. Most of the power requirement usage in this section was for beating straw with concave beaters. The beating process creates friction between the rotor and concave. Therefore, it was not necessary to adjust the guide vane inclinations in the output section to more than 70 degrees because the reduction in the power requirement while threshing was not significant.

The concept of pattern 6 was to move material quickly from the input section and move it consistently in the output section. The study by Chuan-udom (2011) found that the guide vane inclinations in the input and output sections should be 60 and 70 degrees, respectively, when threshing the Chainat 1 rice variety because the threshing loss and power requirement would be low. Thus, the guide vane inclinations in the output section were adjusted to lower than 70 degrees; the increase in threshing loss would not be substantial, while it may reduce the power requirement substantially. This concept was in agreement with the study by Gummert *et al.* (1992), who found that the threshing loss tended to increase and the power requirement tended to reduce if the guide vane inclinations were low. Consequently, the guide vane inclinations in the input and output sections were 60 and 68 degrees, respectively, during testing.

Rice conditions and testing conditions

The test used Chainat 1 variety paddy

Table 3 Pattern of guide vane inclination in the study.

Pattern number	Order of angles of guide vane inclination from input (degrees)				
	1st	2nd	3rd	4th	5th
1	69	71	73	75	77
2	69	69	69	69	69
3	68	74	74	68	68
4	60	60	70	70	70
5	60	60	63	66	70
6	60	60	68	68	68

bundles that were obtained from a paddy field in an irrigation area in Khon Kaen during July, 2012. The average grain and straw moisture contents were 28.3 and 51.8% wet basis, respectively. The ratio of grain-to-straw by fresh weight was on average 0.61. The average length of rice stalks was 52 cm.

Testing method

Testing of each pattern of guide vane inclination involved three replications, each using 30 kg of paddy bundles. The discharge was collected using a large net over the end of the threshing unit to gather the output (Figure 3). Then, the output was sorted into grain sticking to ears and grain separated from ears. Grain passing through the mesh fell onto a tray with long cavities to receive the paddy rice (Figure 4). The grain was cleaned (Figure 5) and 2 kg samples in each replicate were taken to quantify breakages. The threshing loss was determined.

Figure 3 Large net used to gather output.

Figure 4 Tray with long cavities to receive paddy rice from threshing unit.

Result indicators

The indicators from the study were:

Threshing loss: the ratio of grain-on-ear weight and grain weight discharged from output-to-grain weight collected under threshing mesh after cleaning was determined using Equation 2:

$$TL = [B / (A+B)] \times 100 \quad (2)$$

where, TL is the threshing loss (%), A is the weight of threshed grain (whole and damage grain) per unit time collected at the main grain outlet in grams and B is the weight of the threshed and unthreshed grain per unit time collected at the straw outlet per unit time in grams.

Power requirement: calculated from the value obtained from torque gauging using Equation 3:

$$P = (T \times n \times 2\pi) / 60 \quad (3)$$

where, P is the power requirement in kilowatts, T is the electric motor torque in kilonewton-meters and n is the rotor speed in revolutions per minute.

Grain breakage: the ratio of broken grain weight after threshing to weight-of-grain

Figure 5 Manually assisted cleaning and separation of the grain.

sampled from the tray beneath the threshing mesh was determined using Equation 4:

$$GB = (E/C) \times 100 \quad (4)$$

where, GB is the grain breakage (%), E is the weight or quantity of grain breakage collected at the main grain outlet in grams, C is the random weight of threshed grain (whole and damaged grain) per unit time collected at the main grain outlet in grams.

RESULTS AND DISCUSSION

Results of guide vane inclination adjustments of rice combine harvesters

Most of the 17 rice combine harvesters surveyed were in the northeast, lower north and central parts of Thailand. The rice combine harvesters had 4 or 5 guide vane inclinations. The results of the guide vane inclination patterns are shown in Table 1. These patterns can be classified into three groups: Group 1, the guide vane inclination of the first three blades from the input was smaller than the last two blades; Group 2, the guide vane inclination of all blades was similar; and Group 3, the guide vane inclinations of the first and the last blades were smaller than those of the blades at the center of the threshing chamber.

The guide vane inclinations of five rice combine harvesters (29.4% of all harvesters surveyed) were of the Group 1 pattern, with the inclinations of the first, second and third blades being smaller than that of the fourth and fifth blades. There were 10 harvesters (58.8%) in the Group 2 pattern, with a similar average guide vane inclination. The other two harvesters (11.8%) used the guide vane inclination of Pattern 3 (Table 2).

From the analysis of the guide vane inclination patterns and adjustment concepts, it was found that:

Group 1: the concept was for paddy bundles to move quickly into the threshing chamber and to spend more time in threshing and separating grain from ear in the last section of chamber.

Group 2: the concept of the guide vane inclination adjustment was for paddy bundles to move consistently into the threshing chamber. The inclination angle was 69 degrees, which was appropriate since an angle lower than 64 degrees resulted in rapid flow of paddy bundles away from the threshing chamber, which resulted in excessive loss (Chuan-Udom and Chinsuwan, 2009).

Group 3: the concept of the guide vane inclination adjustment was for paddy bundles to move into and out of the threshing chamber in a short time. The guide vane inclinations at the center of the chamber were increased to lengthen the time for threshing and separating grain from ear.

Effect of adjustments to the guide vane inclination of rice combine harvesters on the threshing loss and power requirement

The test resulted in the guide vane inclination patterns affecting the threshing loss over a range from 2.34 to 6.95%, resulting in grain breakage from 0.026 to 0.058%. The power requirement ranged from 18.17 to 20.06 kW, as shown in Table 5.

With respect to threshing loss, pattern 1 with a constant increase of inclination of 69, 71, 73, 75, and 77 degrees (or pattern 69-71-73-75-77) yielded the lowest loss at an average of 2.34%. This was followed by pattern 3, with the angles of the two blades at the input section of 68 and 74 degrees and the angles of the three blades at the output section of 74, 68, and 68 degrees (or pattern 68-74-74-68-68) which yielded the second lowest loss at an average of 2.59%. Patterns 2, 4, 5, and 6 yielded losses of 4.30, 5.39, 4.92, and 6.95%, respectively. The threshing loss of patterns 1 and 3 were lower than for patterns 2, 4, 5, and 6, because of the average of the angles in the middle of patterns 1 and 3 (the second, third and fourth blades) which were 73 and 72 degrees for patterns 1 and 3, respectively, were higher than those of patterns 2, 4, 5 and 6 which were 68, 67, 63 and

69 degrees, respectively. These results agreed with the findings from the study by Waingvisad *et al.* (2011) on the effects of a spike-tooth pattern and louver inclination in an axial flow rice combine harvester on threshing losses, which showed that the angle of the guide vane inclination should not be less than 72 degrees to yield a low threshing loss. The results also agreed with the findings from the studies by Chuan-udom and Chinsuwan (2009) and Harrison (1991), which showed that the guide vane inclination had an impact on the threshing loss.

In terms of the power requirement, pattern 5 with the angles of the two blades of the input section at 60 degrees and the angles of the three blades of the output section at 63, 66, and 70 degrees (or Pattern 60-60-63-66-70) required the least power (average 18.17 kW). In pattern 6, the angles of the two blades of the input section at 60 degrees and the angles of the three blades of the output section at 68 degrees (or pattern 60-60-68-68-68) required the second lowest power requirement of 18.99 kW. The third lowest power requirement came from pattern 4 (19.11 kW) with the angles of the two blades of the input section at 60 degrees and the angles of the 3 blades of the output section at 70 degrees (or pattern 60-60-70-70-70). Patterns 1, 2 and 3 required average power requirements of 19.90, 19.71 and 20.06 kW, respectively. When grain breakage was taken into account, the change in the patterns of adjustment rarely affected breakages (Table 5). The findings correlated with the study by Chuan-udom and Chinsuwan (2011), who considered the effects of operating factors of an axial flow rice combine harvester on grain breakage. The results showed that the guide vane inclination had little effect on grain breakages, whereas all patterns of guide vane inclination adjustments had highly significant ($P < 0.01$) effects on the power requirement.

Analysis of variance was conducted on the six patterns of guide vane inclinations (Table 4) and showed that the patterns under study did not have any effect on grain breakages, but they did have significant impact on threshing loss ($P < 0.05$) and power requirement ($P < 0.01$). Again, this correlated to the study by Chuan-udom and Chinsuwan (2011), which showed that the guide vane inclination had little effect on grain breakages, whereas all patterns of guide vane inclination adjustment had a highly significant ($P < 0.01$) effect on power requirement.

Analysis of variance is presented in Table 4. When comparing the patterns of the effect of guide vane inclination on the threshing loss and power requirements (Table 5), pattern 6 yielded the highest threshing loss, but was not significantly ($P > 0.05$) different from pattern 4, while patterns 1, 2, 3 and 5 showed significantly lower threshing losses.

Pattern 3 required the highest threshing power but this was not significantly ($P > 0.05$) different from pattern 1, while patterns 2, 4 and 6 showed lower power requirements. The power requirement for pattern 5 was the lowest.

After comparing the threshing losses and power requirements without taking into account grain breakages, it was found that patterns 2, 4, 5 and 6 were not suitable for the rice combine harvesters for the Chainat 1 rice variety because those guide vane inclinations gave threshing losses in excess of 4% which was more than the Thai Industrial Standards Institute (2002) standards for axial flow threshers and hence lessened the amount

Table 4 Results of effects of guide vane inclination study on threshing performance of axial flow threshing unit.

Variance source	Threshing loss	Grain breakages	Power requirement
Blocks	0.551 ns	1.594 ns	2.275 ns
Guide vane inclination patterns	3.987 *	0.749 ns	9.816 **

ns = Not significant, * = Significant at the 95% level, ** = Highly significant at the 99% level.

Table 5 Effect of guide vane inclination on performance of threshing unit of axial flow threshing unit and comparison of averages.

Pattern number	Average threshing loss (%)	Average grain breakage (%)	Average power requirement (kW)
1	2.34 ^{a}	0.052 ^{a}	19.90 ^{c}
2	4.30 ^{abc}	0.030 ^{a}	19.71 ^{bc}
3	2.59 ^{ab}	0.052 ^{a}	20.06 ^{c}
4	5.39 ^{bc}	0.030 ^{a}	19.11 ^{b}
5	4.92 ^{abc}	0.058 ^{a}	18.17 ^{a}
6	6.95 ^{c}	0.040 ^{a}	18.99 ^{b}

Mean values followed by the same letter within the same column were not significantly different at the 5% test level, using Duncan's multiple range test.

and quality in rice production. It was found that the power requirements of all patterns were different. Pattern 3 required the highest power and so was not suitable to be used with a rice combine harvester because an unnecessary load would be added during harvesting which would result in high fuel consumption, wear of engine, and thus a higher cost from fuel and maintenance. The choice was between patterns 1 and 2, which showed similar power requirements, though pattern 1 produced a lower threshing loss.

Analysis and comparison of threshing losses and power requirements revealed that harvesting of the Chainat 1 rice variety should use a pattern with a consistent increase in the guide vane inclination, that is, 69, 71, 73, 75 and 77 degrees (pattern 1), so that there was less than 3% threshing loss and the power requirement was not too high when the rotor speed was 18 $m.s^{-1}$ and the feed rate was 16 $t.hr^{-1}$.

CONCLUSION

1. The study on the patterns of guide vane inclinations of rice combine harvesters with 4 to 5 guide vane inclinations showed three groups of patterns: Group 1, where the guide vane inclination of the first 3 blades from the input was smaller than the last 2 blades; Group 2, where the guide vane inclination of all blades on average was similar; and Group 3, where the guide vane inclination of the first and the last blades from the input was smaller than the blades at the center of the threshing chamber. The adjustment percentages of the guide vane inclination in Groups 1, 2 and 3 were 29.4, 58.8 and 11.8%, respectively.

2. The patterns of the guide vane inclination studied did not have any significant effect on grain breakages, but they had a significant effect on the threshing loss and power requirement.

3. The pattern of guide vane inclination of axial flow rice threshing units for harvesting Chainat 1 rice variety should be one where the inclination angles consistently increase from 69, 71, 73, 75, and 77 degrees when the rotor speed is 18 $m.s^{-1}$ and the feed rate is 16 $t.hr^{-1}$.

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